§ XI. *The Spectrum as laid down on* NEWTON'S *Diagram.*

The curve on which these points lie has this striking feature, that two portions of it are nearly, if not quite, straight lines. One of these portions extends from (24) to (46), and the other from (48) to (64). The colour (20), and those beyond (64), are not far from the line joining (24) and (68). The spectrum, therefore, as exhibited in NEWTON'S diagram, forms two sides of a triangle, with doubtful fragments of the third side. Now if three colours in NEWTON'S diagram lie in a straight line, the middle one is a compound of the two others. Hence all the colours of the spectrum may be compounded of those which lie at the angles of this triangle. These correspond to the following colours:—

TABLE VII.

		Scale.	Wave-length.	Index in water.	Wave-length in water.
R	Scarlet . .	24	2328	1·332	1·747
G	Green . . .	$46\frac{3}{4}$	1914	1·334	1·435
B	Blue . . .	$64\frac{1}{2}$	1717	1·339	1·282

All the other colours of the spectrum may be produced by combinations of these; and since all natural colours are compounded of the colours of the spectrum, they may be compounded of these three primary colours. I have strong reason to believe that these are the three primary colours corresponding to three modes of sensation in the organ of vision, on which the whole system of colour, as seen by the normal eye, depends.

§ XII. *Results found by a second Observer.*

We may now consider the results of three series of observations made by myself (J.) as observer, in order to determine the relation of one observer to another in the perception of colour. The standard colours are connected by the following equation, as determined by six observations:—

$$18{\cdot}1(24)+27{\cdot}5(44)+37(68)=W^{*}. \quad \ldots\ldots\ldots \quad (17.)$$

The average errors in these observations were—

TABLE VIII.

R, ·28	G+B, ·83	G−B, ·83	
G, ·83	B+R, ·42	B−R, ·28	R+G+B, ·95
B, ·16	R+G, ·95	R−G, ·72	

showing that in this case, also, the power of distinguishing *colour* is more to be depended on than that of distinguishing degrees of *illumination.*

The average error in the other observations from the means was ·64 for red, ·76 for green, and 1·02 for blue.

TABLE IX.

Observations by J., October 1859.

	(24.)	(44.)	(68.)
44·3(20)=	18·1	−2·5	+2·3
16·0(28)=	18·1	+6·2	−0·7
21·5(32)=	18·1	+25·2	−0·7
19·3(36)=	8·1	+27·5	−0·3
20·7(40)=	2·1	+27·5	−0·5
52·3(48)=	−1·4	+27·5	+10·7
95·0(52)=	−2·4	+27·5	+37·0
51·7(56)=	−2·2	+4·8	+37·0
37·2(60)=	−1·2	+0·8	+37·0
36·7(64)=	−0·2	+0·8	+37·0
35·0(72)=	+0·6	−0·2	+37·0
40·0(76)=	+0·9	+0·5	+37·0
51·0(80)=	+1·1	+0·5	+37·0

§ XIII. *Comparison of Results by* NEWTON'S *Diagram.*

The relations of the colours, as given by these observations, are laid down in fig. 5, Plate I. It appears from this diagram, that the positions of the colours lie nearly in a straight line from (24) to (44), and from (48) to (60). The colours beyond (60) are crowded together, as in the other diagram, and the observations are not yet sufficiently accurate to distinguish their relative positions accurately. The colour (20) at the red end of the spectrum is further from the line joining (24) and (68) than in the other diagram, but I have not obtained satisfactory observations of these extreme colours. It will be observed that (32), (36), and (40) are placed further to the right in fig. 5 than in fig. 4, showing that the second observer (J.) sees more green in these colours than the first (K.), also that (48), (52), (56), and (60) are much further up in fig. 5, showing that to the second observer they appear more blue and less green. These differences were well seen in making an observation. When the instrument was adjusted to suit the first observer (K.), then, if the selected colour were (32), (36), or (40), the second (J.), on looking into the instrument, saw it too green; but if (48), (52), (56), or (60) were the selected colour, then, if right to the first observer, it appeared too blue to the second. If the instrument were adjusted to suit the second observer, then, in the first case, the other saw red, and in the second green; showing that there was a real difference in the eyes of these two individuals, producing constant and measurable differences in the apparent colour of objects.

§ XIV. *Comparison by Curves of Intensity of the Primaries.*

Figs. 6 and 7, Plate I., are intended to indicate the intensities of the three standard colours at different points of the spectrum. The curve marked (R) indicates the intensity of the red or (24), (G) that of green or (44), and (B) that of blue or (68). The curve marked (S) has its ordinates equal to the sum of the ordinates of the other three curves. The intensities are found by dividing every colour-equation by the coefficient of the colour on the left-hand side. Fig. 6 represents the results of observations by K, and fig. 7 represents those of J. It will be observed that the ordinates in fig. 7 are smaller between (48) and (56) than in fig. 6. This indicates the feeble intensity of certain kinds of light as seen by the eyes of J, which made it impossible to get observations of the colour (52) at all without making the slit so wide as to include all between (48) and (56).

This blindness of my eyes to the parts of the spectrum between the fixed lines E and F appears to be confined to the region surrounding the axis of vision, as the field of view, when adjusted for my eyes looking directly at the colour, is decidedly out of adjustment when I view it by indirect vision, turning the axis of my eye towards some other point. The prism then appears greener and brighter than the mirror, showing that the parts of my eye at a distance from the axis are more sensitive to this blue-green light than the parts close to the axis.

It is to be noticed that this insensibility is not to all light of a green or blue colour, but to light of a definite refrangibility. If I had a species of colour-blindness rendering me totally or partially insensible to that element of colour which most nearly corresponds with the light in question, then the light from the mirror, as well as that from the prism, would appear to me deficient in that colour, and I should still consider them chromatically identical; or if there were any difference, it would be the same for all colours nearly the same in appearance, such as those just beyond the line F, which appear to me quite bright.

We must also observe that the peculiarity is confined to a certain portion of the retina, which is known to be of a yellow colour, and which is the seat of several ocular phenomena observed by PURKINJE and WHEATSTONE, and of the sheaf or brushes seen by HAIDINGER in polarized light; and also that though, of the two observers whose results are given here, one is much more affected with this peculiarity than the other, both are less sensible to the light between E and F than to that on either side; and other observers, whose results are not here given, confirm this.

§ XV. *Explanation of the Differences between the two Observers.*

I think, therefore, that the yellow spot at the foramen centrale of SOEMMERING will be found to be the cause of this phenomenon, and that it absorbs the rays between E and F, and would, if placed in the path of the incident light, produce a corresponding dark band in the spectrum formed by a prism.

The reason why white light does not appear yellow in consequence, is that this absorbing action is constant, and we reckon as white the *mean* of all the colours we are accustomed to see. This may be proved by wearing spectacles of any strong colour for some time, when we shall find that we judge white objects to be white, in spite of the rays which enter the eye being coloured.

Now ordinary white light is a mixture of all kinds of light, including that between E and F, which is partially absorbed. If, therefore, we compound an artificial white containing the absorbed ray as one of its three components, it will be much more altered by the absorption than the ordinary light, which contains many rays of nearly the same colour, which are not absorbed. On the other hand, if the artificial light do not contain the absorbed ray, it will be less altered than the ordinary light which contains it. Hence the greater the absorption the less green will those colours appear which are near the absorbed part, such as (48), (52), (56), and the more green will the colours appear which are not near it, such as (32), (36), (40). And these are the chief differences between fig. 4 and fig. 5.

I first observed this peculiarity of my eyes when observing the spectrum formed by a very long vertical slit. I saw an elongated dark spot running up and down in the blue, as if confined in a groove, and following the motion of the eye as it moved up or down the spectrum, but refusing to pass out of the blue into other colours. By increasing the breadth of the spectrum, the dark portion was found to correspond to the *foramen centrale*, and to be visible only when the eye is turned towards the blue-green between E and F. The spot may be well seen by first looking at a yellow paper, and then at a blue one, when the spot will be distinctly seen for a short time, but it soon disappears when the eye gets accustomed to the blue*.

I have been the more careful in stating this peculiarity of my eyes, as I have reason to believe that it affects most persons, especially those who can see HAIDINGER'S brushes easily. Such persons, in comparing their vision with that of others, may be led to think themselves affected with partial colour-blindness, whereas their colour-vision may be of the ordinary kind, but the rays which reach their sense of sight may be more or less altered in their proportions by passing through the media of the eye. The existence of real, though partial colour-blindness will make itself apparent, in a series of observations, by the discrepancy between the observed values and the means being greater in certain colours than in others.

§ XVI. *General Conclusions.*

Neither of the observers whose results are given here show any indications of colour-blindness, and when the differences arising from the absorption of the rays between E and F are put out of account, they agree in proving that there are three colours in the spectrum, red, green, and blue, by the mixtures of which colours chromatically identical with the other colours of the spectrum may be produced. The exact position of the red and blue is not yet ascertained; that of the green is $\frac{1}{4}$ from E towards F.

The orange and yellow of the spectrum are chromatically equivalent to mixtures of red and green. They are neither richer nor paler than the corresponding mixtures, and the only difference is that the mixture may be resolved by a prism, whereas the colour

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* See the Report of the British Association for 1856, p. 12.

in the spectrum cannot be so resolved. This result seems to put an end to the pretension of yellow to be considered a primary element of colour.

In the same way the colours from the primary green to blue are chromatically identical with mixtures of these; and the extreme ends of the spectrum are probably equivalent to mixtures of red and blue, but they are so feeble in illumination that experiments on the same plan with the rest can give no result, but they must be examined by some special method. When observations have been obtained from a greater number of individuals, including those whose vision is dichromatic, the chart of the spectrum may be laid down independently of accidental differences, and a more complete discussion of the laws of the sensation of colour attempted.

POSTSCRIPT.

Received May 8,—Read May 24, 1860.

Since sending the above paper to the Royal Society, I have obtained some observations of the colour of the spectrum by persons whose vision is "dichromic," and who are therefore said to be "colour-blind."

The instrument used in making these observations was similar in principle to that formerly described, except that, in order to render it portable, the rays are reflected back through the prisms, nearly in their original direction; thus rendering one of the limbs of the instrument unnecessary, and allowing the other to be shortened considerably on account of the greater angular dispersion. The principle of reflecting light, so as to pass twice through the same prism, was employed by me in an instrument for combining colours made in 1856, and a reflecting instrument for observing the spectrum has been constructed independently by M. Porro.

Light from a sheet of paper illuminated by sunlight is admitted at the slits X, Y, Z (fig. 8, Plate II.), falls on the prisms P and P′ (angles$=45°$), then on a concave silvered glass, S, radius 34 inches. The light, after reflexion, passes again through the prisms P′ and P, and is reflected by a small mirror, *e*, to the slit E, where the eye is placed to receive the light compounded of the colours corresponding to the positions and breadths of the slits X, Y, and Z.

At the same time, another portion of the light from the illuminated paper enters the instrument at BC, is reflected at the mirror M, passes through the lens L, is reflected at the mirror M′, passes close to the edge of the prism P, and is reflected along with the coloured light at *e*, to the eye-slit at E.

In this way the compound colour is compared with a constant white light in optical juxtaposition with it. The mirror M is made of silvered glass, that at M′ is made of glass roughened and blackened at the back, to reduce the intensity of the constant light to a convenient value for the experiments.

This instrument gives a spectrum in which the lines are very distinct, and the length of the spectrum from A to H is 3·6 inches. The outside measure of the box is 3 feet 6 inches, by 11 inches by 4 inches, and it can be carried about, and set up in any position, without readjustment. It was made by Messrs. SMITH and RAMAGE of Aberdeen.

In obtaining observations from colour-blind persons, two slits only are required to produce a mixture chromatically equivalent to white; and at one point of the spectrum the colour of the pure rays appears identical with white. This point is near the line F, a little on the less refrangible side. From this point to the more refrangible end of the spectrum appears to them "blue." The colours on the less refrangible side appear to them all of the same quality, but of different degrees of brightness; and when any of them are made sufficiently bright, they are called "yellow." It is convenient to use the term "yellow" in speaking of the colours from red to green inclusive, since it will be found that a dichromic person in speaking of red, green, orange, and brown, refers to different degrees of brightness or purity of a single colour, and not to different colours perceived by him. This colour we may agree to call "yellow," though it is not probable that the sensation of it is like that of yellow as perceived by us.

Of the three standard colours which I formerly assumed, the red appears to them "yellow," but so feeble that there is not enough in the whole red division of the spectrum to form an equivalent to make up the standard white. The green at E appears a good "yellow," and the blue at $\frac{1}{3}$ from F towards G appears a good "blue." I have therefore taken these as standard colours for reducing dichromic observations. The three standard colours will be referred to as (104), (88), and (68), these being the positions of the red, green, and blue on the scale of the new instrument.

Mr. JAMES SIMPSON, formerly student of Natural Philosophy in my class, has furnished me with thirty-three observations taken in good sunlight. Ten of these were between the two standard colours, and give the following result:—

$$33{\cdot}7(88)+33{\cdot}1(68)=W. \quad \dots \dots \quad (1.)$$

The mean errors of these observations were as follows:—

Error of $(88)=2{\cdot}5$; of $(68)=2{\cdot}3$; of $(88)+(68)=4{\cdot}8$; of $(88)-(68)=1{\cdot}3$.

The fact that the mean error of the sum was so much greater than the mean error of the difference, indicates that in this case, as in all others that I have examined, observations of equality of tint can be depended on much more than observations of equality of illumination or brightness.

From six observations of my own, made at the same time, I have deduced the "trichromic" equation

$$22{\cdot}6(104)+26(88)+37{\cdot}4(68)=W. \quad \dots \dots \quad (2.)$$

If we suppose that the light which reached the organ of vision was the same in both cases, we may combine these equations by subtraction, and so find

$$22{\cdot}6(104)-7{\cdot}7(88)+4{\cdot}3(68)=D, \quad \dots \dots \quad (3.)$$

where D is that colour, the absence of the sensation of which constitutes the defect of the dichromic eye. The sensation which I have in addition to those of the dichromic eye is therefore similar to the full red (104), but different from it, in that the red (104) has 7·7 of green (88) in it which must be removed, and 4·3 of blue (68) substituted. This agrees pretty well with the colour which Mr. POLE* describes as neutral to him, though crimson to others. It must be remembered, however, that different persons of ordinary vision require different proportions of the standard colours, probably owing to differences in the absorptive powers of the media of the eye, and that the above equation (2.), if observed by K, would have been

$$23(104)+32(88)+31(68)=W; \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4.)$$

and the value of D, as deduced from these observers, would have been

$$23(104)-1{\cdot}7(88)-1{\cdot}1(68)=D, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5.)$$

in which the defective sensation is much nearer to the red of the spectrum. It is probably a colour to which the extreme red of the spectrum tends, and which differs from the extreme red only in not containing that small proportion of "yellow" light which renders it visible to the colour-blind.

From other observations by Mr. SIMPSON the following results have been deduced:—

TABLE *a*.

	(88).	(68).
(99·2+)=	33·7	1·9
31·3(96)=	33·7	2·1
28 (92)=	33·7	1·4
33·7(88)=	33·7	0
54·7(84)=	33·7	6·1
71 (82)=	33·7	15·1
99 (80)=	33·7	33·1
70 (78)=	15·7	33·1
56 (76)=	5·7	33·1
36 (72)=	− 0·3	33·1
33·1(68)=	0	33·1
40 (64)=	0·2	33·1
55·5(60)=	1·7	33·1
(57−) =	− 0·3	33·1

	(88).	(68).
100(96)=	108	7
100(92)=	120	5
100(88)=	100	0
100(84)=	61	11
100(82)=	47	21
100(80)=	34	33
100(78)=	22	47
100(76)=	10	59
100(72)=	− 1	92
100(68)=	0	100
100(64)=	0	83
100(60)=	3	60

In the Table on the left side (99·2+) means the whole of the spectrum beyond (99·2) on the scale, and (57−) means the whole beyond (57) on the scale. The position of the fixed lines with reference to the scale was as follows:—

A, 116; *a*, 112; B, 110; C, 106; D, 98·3; E, 88; F, 79; G, 61; H, 44.

The values of the standard colours in different parts of the spectrum are given on the

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* Philosophical Transactions, 1859, Part I. p. 329.

right side of the above Table, and are represented by the curves of fig. 9, Plate II., where the left-hand curve represents the intensity of the "yellow" element, and the right-hand curve that of the "blue" element of colour as it appears to the colour-blind.

The appearance of the spectrum to the colour-blind is as follows:—

From A to E the colour is pure "yellow" very faint up to D, and reaching a maximum between D and E. From E to one-third beyond F towards G the colour is mixed, varying from "yellow" to "blue," and becoming neutral or "white" at a point near F. In this part of the spectrum, the total intensity, as given by the dotted line, is decidedly less than on either side of it, and near the line F, the retina close to the "yellow spot" is less sensible to light than the parts further from the axis of the eye. This peculiarity of the light near F is even more marked in the colour-blind than in the ordinary eye. Beyond F the "blue" element comes to a maximum between F and G, and then diminishes towards H; the spectrum from this maximum to the end being pure "blue."

In fig. 10, Plate II. these results are represented in a different manner. The point D, corresponding to the sensation wanting in the colour-blind, is taken as the origin of coordinates, the "yellow" element of colour is represented by distances measured horizontally to the right from D, and the "blue" element by distances measured vertically from the horizontal line through D. The numerals indicate the different colours of the spectrum according to the scale shown in fig. 9, and the coordinates of each point indicate the composition of the corresponding colour. The triangle of colours is reduced, in the case of dichromic vision, to a straight line "B" "Y," and the proportions of "blue" and "yellow" in each colour are indicated by the ratios in which this line is cut by the line from D passing through the position of that colour.

The results given above were all obtained with the light of white paper, placed in clear sunshine. I have obtained similar results, when the sun was hidden, by using the light of uniformly illuminated clouds, but I do not consider these observations sufficiently free from disturbing circumstances to be employed in calculation. It is easy, however, by means of such observations, to verify the most remarkable phenomena of colour-blindness, as for instance, that the colours from red to green appear to differ only in brightness, and that the brightness may be made identical by changing the width of the slit; that the colour near F is a neutral tint, and that the eye in viewing it sees a dark spot in the direction of the axis of vision; that the colours beyond are all blue of different intensities, and that any "blue" may be combined with any "yellow" in such proportions as to form "white." These results I have verified by the observations of another colour-blind gentleman, who did not obtain sunlight for his observations; and as I have now the means of carrying the requisite apparatus easily, I hope to meet with other colour-blind observers, and to obtain their observations under more favourable circumstances.

On the Comparison of Colour-blind with ordinary Vision by means of Observations with Coloured Papers.

In March 1859 I obtained a set of observations by Mr. Simpson, of the relations between six coloured papers as seen by him. The experiments were made with the colour-top in the manner described in my paper in the Transactions of the Royal Society of Edinburgh, vol. xxi. pt. 2. p. 286; and the colour-equations were arranged so as to be equated to zero, as in those given in the Philosophical Magazine, July 1857. The colours were,—Vermilion (V), ultramarine (U), emerald-green (G), ivory-black (B), snow-white (W), and pale chrome-yellow (Y). These six colours afford fifteen colour-blind equations, since four colours enter into each equation. Fourteen of these were observed by Mr. SIMPSON, and from these I deduced three equations, giving the relation of the three standards (V), (U), (G) to the other colours, according to his kind of vision. From these three equations I then deduced fifteen equations, admitting of comparison with the observed equations, and necessarily consistent in themselves.

The comparison of these equations furnishes a test of the truth of the theory that the colour-blind see by means of two colour-sensations, and that therefore every colour may be expressed in terms of *two* given colours, just as in ordinary vision it may be expressed in terms of three given colours. The one set of equations are each the result of a single observation; the other set are deduced from three equations in accordance with this theory, and the two sets agree to within an average error =2·1.

TABLE *b*.

	V.	U.	G.	B.	W.	Y.	
1. Observed . . .	0	0	−100	+45	+22	+33	=0.
Calculated . .	0	0	−100	+37·5	+26·5	+36	=0.
2. Observed . . .	0	+58	0	−69	−31	+42	=0.
Calculated . .	0	+58·3	0	−67·3	−32·7	+41·7	=0.
3. Observed . . .	0	+32	−100	0	+12	+56	=0.
Calculated . .	0	+32·3	−100	0	+ 8·3	+59·4	=0.
4. Observed . . .	0	+38	− 89	−11	0	+62	=0.
Calculated . .	0	+40	− 85	−15	0	+60	=0.
5. Observed . . .	0	+32	+ 68	−60	−40	0	=0.
Calculated . .	0	+34	+ 66	−63·5	−36·5	0	=0.
6. Observed . . .	−100	0	0	+82	+ 5	+13	=0.
Calculated . .	−100	0	0	+83·9	+ 4·5	+11·6	=0.
7. Observed . . .	+ 47	0	−100	0	+22	+31	=0.
Calculated . .	+ 44·7	0	−100	0	+24·5	+30·8	=0.
8. Observed . . .	−100	0	+ 20	+77	0	+ 3	=0.
Calculated . .	−100	0	+ 17	+77·5	0	+ 5·5	=0.
9. Not observed.							
Calculated . .	+ 96	0	− 31	−69	+ 4	0	=0.

TABLE *b* (continued).

	V.	U.	G.	B.	W.	Y.
10. Observed . . .	− 70	+53	0	0	−30	+47 =0.
Calculated . .	− 73·5	+53	0	0	−26·5	+47 =0.
11. Observed . . .	−100	+ 8	0	+71	0	+21 =0.
Calculated . .	−100	+ 8	0	+74·5	0	+17·5=0.
12. Observed . . .	+ 85	+15	0	−88	−12	0 =0.
Calculated . .	+ 86	+14	0	−88·5	−11·5	0 =0.
13. Observed . . .	− 20	+39	− 80	0	0	+61 =0.
Calculated . .	− 19	+40	− 81	0	0	+60 =0.
14. Observed . . .	− 66	+30	+ 70	0	−34	0 =0.
Calculated . .	− 70	+27	+ 73	0	−30	0 =0.
15. Observed . . .	+100	− 2	− 27	−71	0	0 =0.
Calculated . .	+ 96	+ 4	− 24	−76	0	0 =0.

But, according to our theory, colour-blind vision is not only dichromic, but the two elements of colour are identical with two of the three elements of colour as seen by the ordinary eye; so that it differs from ordinary vision only in not perceiving a particular colour, the relation of which to known colours may be numerically defined. This colour may be expressed under the form

$$aV+bU+cG=D, \qquad (16.)$$

where V, U, and G are the standard colours used in the experiments, and D is the colour which is visible to the ordinary eye, but invisible to the colour-blind. If we know the value of D, we may always change an ordinary colour-equation into a colour-blind equation by subtracting from it nD (n being chosen so that one of the standard colours is eliminated), and adding n of black.

In September 1856 I deduced, from thirty-six observations of my own, the chromatic relations of the same set of six coloured papers. These observations, with a comparison of them with the trichromic theory of vision, are to be found in the 'Philosophical Magazine' for July 1857. The relations of the six colours may be deduced from two equations, of which the most convenient form is

$$\begin{array}{rrrrrrl} \text{V.} & \text{U.} & \text{G.} & \text{B.} & \text{W.} & \text{Y.} & \\ +39{\cdot}7 & +26{\cdot}6 & +33{\cdot}7 & -22{\cdot}7 & -77{\cdot}3 & 0 & =0. \quad (17.) \\ -62{\cdot}4 & +18{\cdot}6 & -37{\cdot}6 & 0 & +45{\cdot}7 & +35{\cdot}7 & =0. \quad (18.) \end{array}$$

The value of D, as deduced from a comparison of these equations with the colour-blind equations, is

$$1{\cdot}198V+0{\cdot}078U-0{\cdot}276G=D. \qquad (19.)$$

By making D the same thing as black (B), and eliminating W and Y respectively from the two ordinary colour-equations by means of D, we obtain three colour-blind equations, calculated from the ordinary equations and consistent with them, supposing that the colour (D) is black to the colour-blind.

The following Table is a comparison of the colour-blind equations deduced from Mr. SIMPSON'S observations alone, with those deduced from my observations and the value of D.

TABLE *c*.

	V.	U.	G.	B.	W.	Y.
(15) Calculated . .	+96	+ 4	−24	−76	0	0
By (19)	+93·9	+ 6·1	−21·7	−78·3	0	0
(14) Calculated . .	−70	+27	+73	0	−30	0
By (17) and (19) . .	−70	+27·2	−72·8	0	−30	0
(13) Calculated . .	−19	+40	−81	0	0	+60
By (18) and (19) . .	−13·6	+38·5	−86·4	0	0	+61·5

The average error here is 1·9, smaller than the average error of the individual colour-blind observations, showing that the theory of colour-blindness being the want of a certain colour-sensation which is one of the three ordinary colour-sensations, agrees with observation to within the limits of error.

In fig. 11, Plate II. I have laid down the chromatic relations of these colours according to NEWTON'S method. V (vermilion), U (ultramarine), and G (emerald-green) are assumed as standard colours, and placed at the angles of an equilateral triangle. The position of W (white) and Y (pale chrome-yellow) with respect to these are laid down from equations (17.) and (18.), deduced from my own observations. The positions of the defective colour, of white, and of yellow, as deduced from Mr. SIMPSON'S equations alone, are given at "*d*," "*w*," and "*y*." The positions of these points, as deduced from a combination of these equations with my own, are given at "D," "W," and "Y." The difference of these positions from those of "*d*," "*w*," and "*y*," shows the amount of discrepancy between observation and theory.

It will be observed that D is situated near V (vermilion), but that a line from D to W cuts UV at C near to V. D is therefore a red colour, not scarlet, but further from yellow. It may be called crimson, and may be *imitated* by a mixture of 86 vermilion and 14 ultramarine. This compound colour will be of the same *hue* as D; but since C lies between D and W, C must be regarded as D diluted with a certain amount of white; and therefore D must be imagined to be like C in hue, but without the intermixture of white which is unavoidable in actual pigments, and which reduces the purity of the tint.

Lines drawn from D through " W " and " Y," the colour-blind positions of white and yellow, pass through W and Y, their positions in ordinary vision. The reason why they do not coincide with W and Y, is that the white and yellow papers are much brighter than the colours corresponding to the points W and Y of the triangle V, U, G; and therefore lines from D, which represent them in intensity as well as in quality, must be longer than DW and DY in the proportion of their brightness.

Mr. MAXWELL'S PAPER.

On Compound Colours.

Phil. Trans. MDCCCLX. *Plate* I.

Fig. 1.

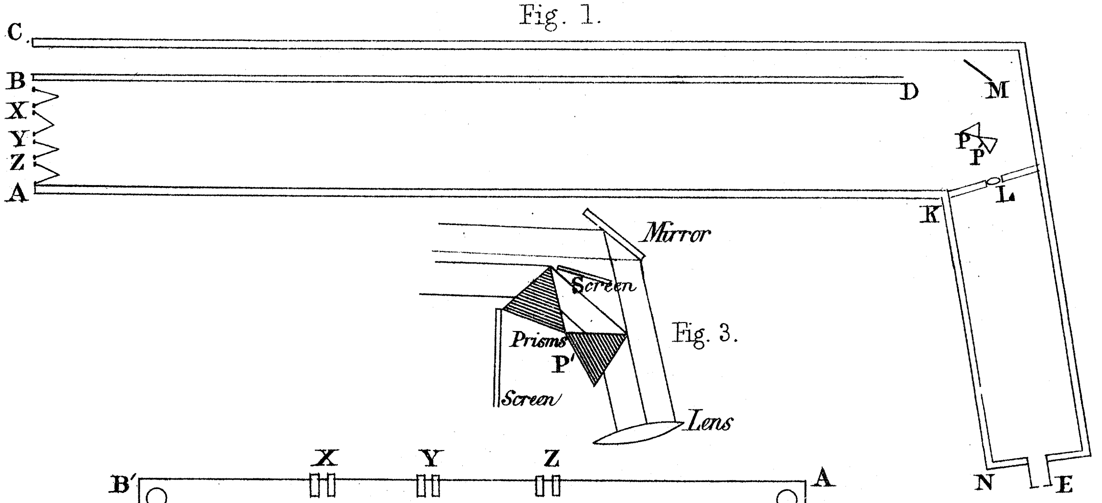


Fig. 3.

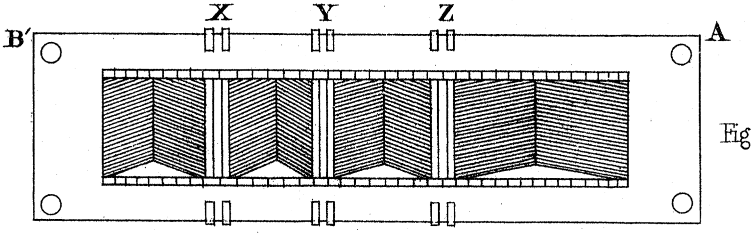


Fig. 2.

Fig. 4.

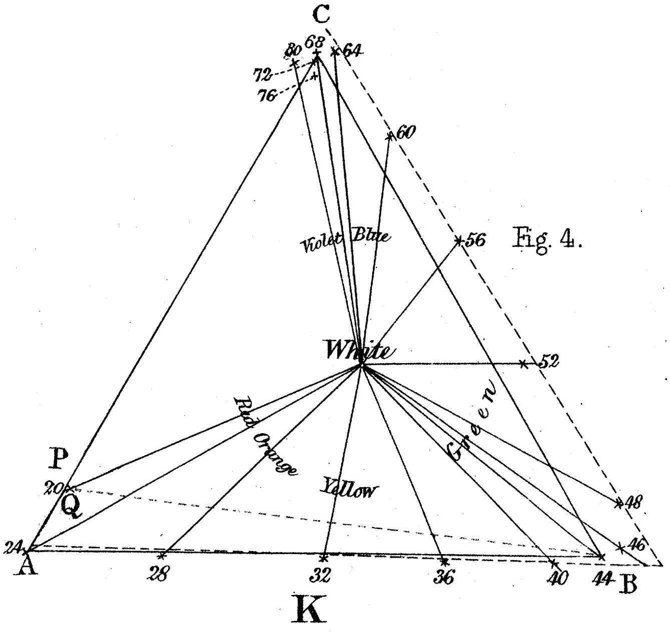


Fig. 5.

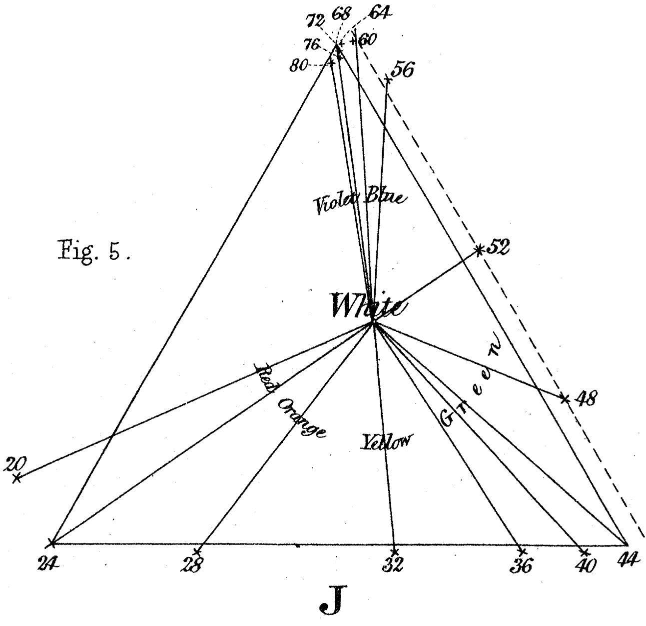


Fig. 6.

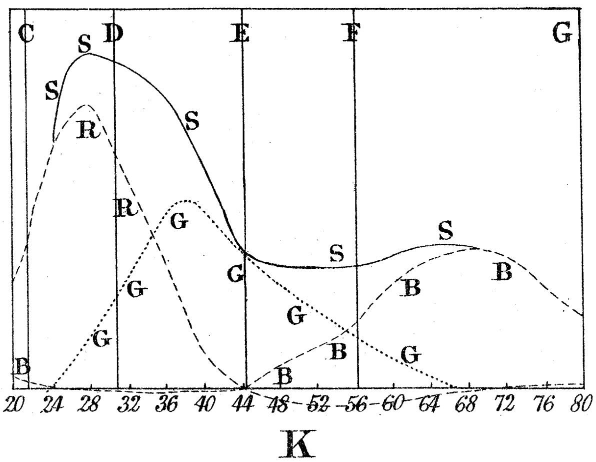
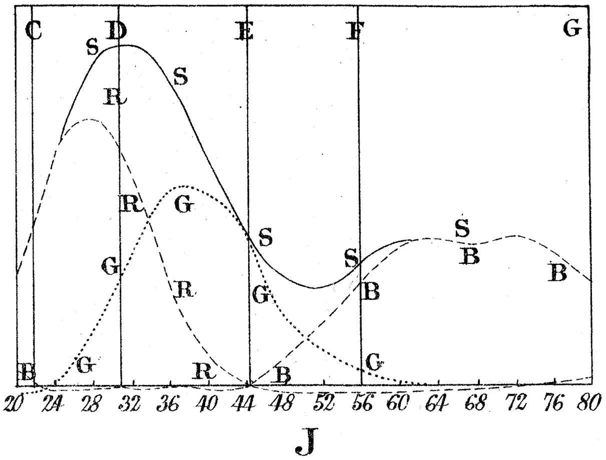


Fig. 7.



J. Basire, lith.

Fig. 8.

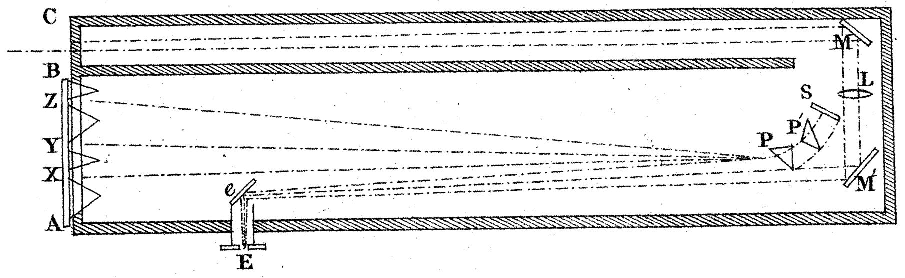
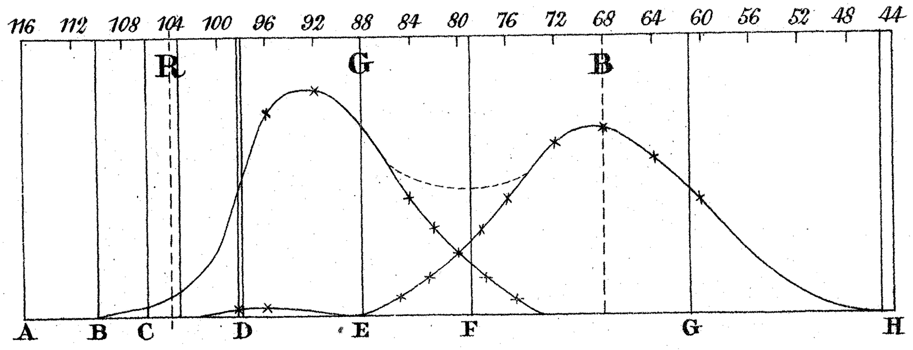


Fig. 9.



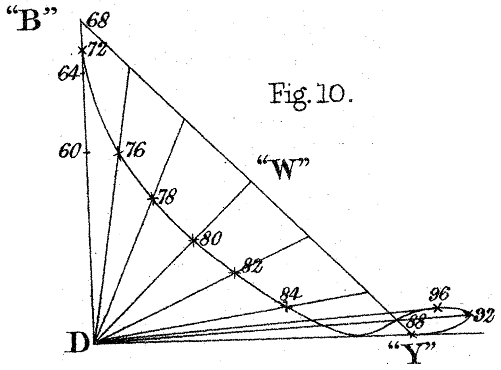
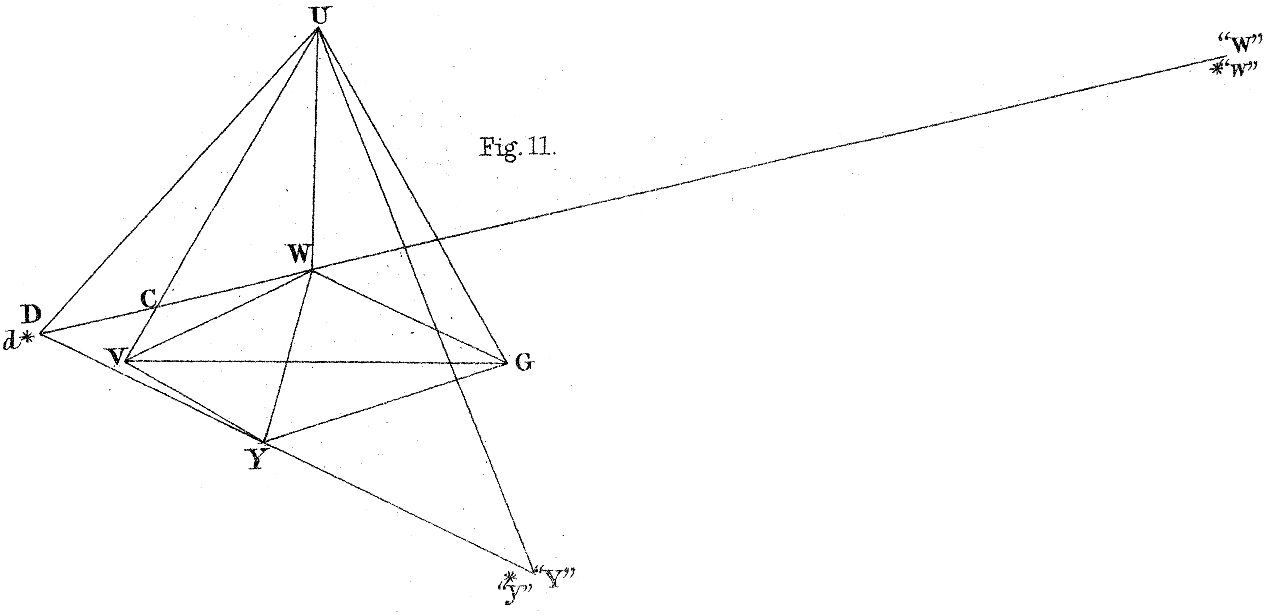


Fig. 10.

Fig. 11.



J. Basire, lith.